Rate-Constrained Beamforming with Application to Hearing Aids

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Outline

Motivations (1/4)

Generalities

- Battery-operated sensing devices
- Types: behind-the-ear (BTE), in-the-ear (ITE), in-the-canal (ITC) and completely-in-the-canal (CTC)

- Analog vs. digital
- 1 to 3 (omni-)directional microphones, 1 loudspeaker

Motivations (2/4)

Goals

- Overcome user's hearing impairment
- Noise reduction
- Improve speech intelligibility
- ...

Motivations (3/4)

How to achieve theses goals?

- Spectral shaping
- Beamforming

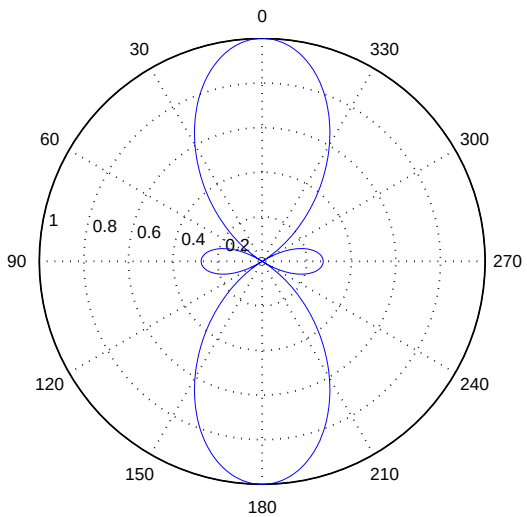

Figure: Example of beampattern at $f = 1000$ [Hz] for 2 microphones separated by d=0.2 [m].

Motivations (4/4)

- Assistive listening devices

(a) (b)

Figure: Assistive listening devices. (a) Remote microphone. (b) Collaborating hearing aids.

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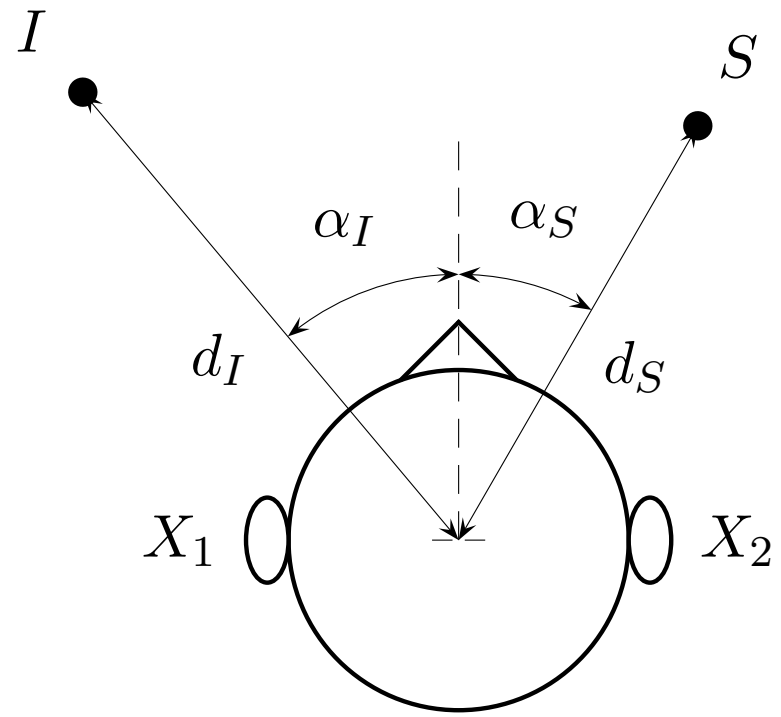
Fundamental gain-rate tradeoff

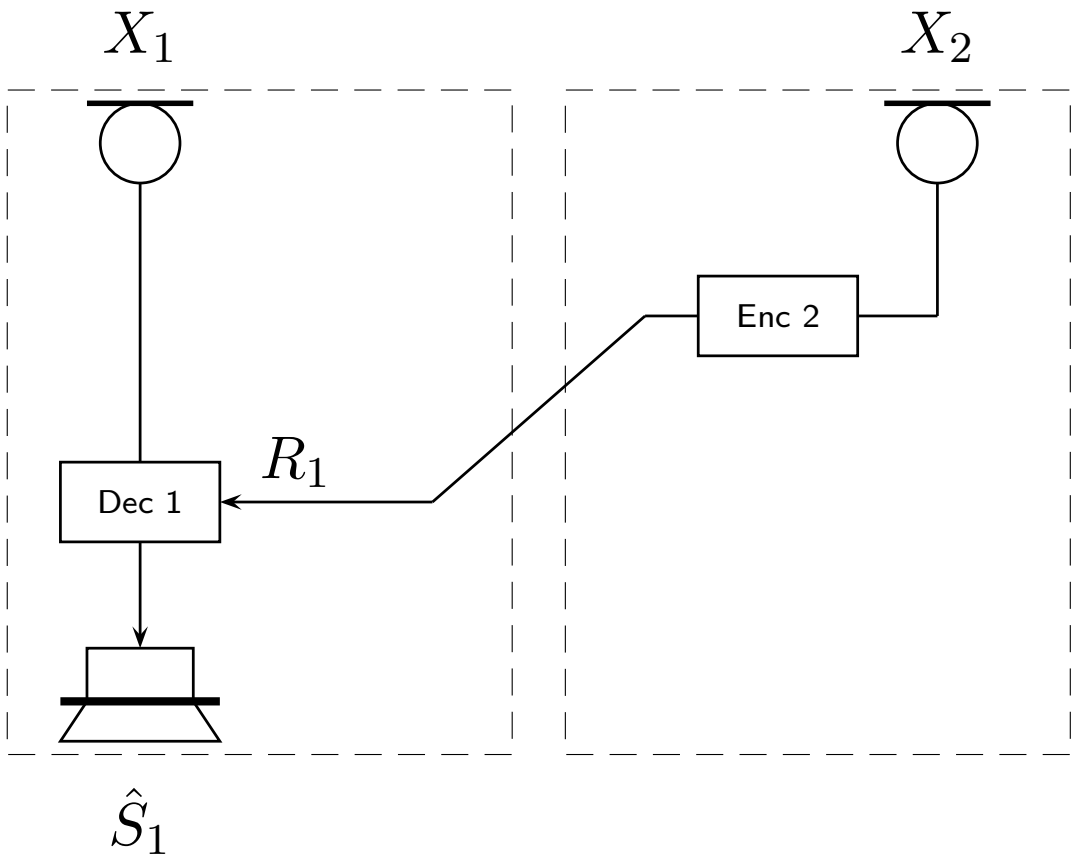
The Rate-Constrained Hearing Aid Problem (1/3)

Head-related configuration



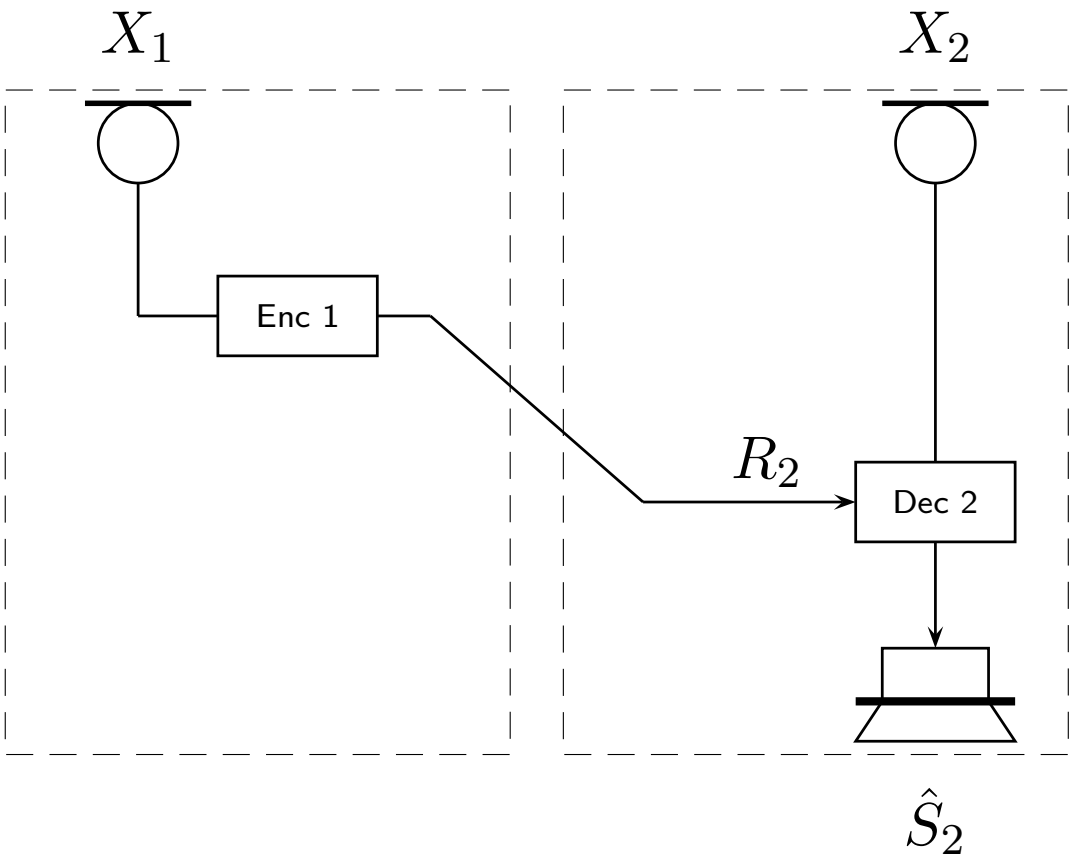
The Rate-Constrained Hearing Aid Problem (2/3)

Local perspective



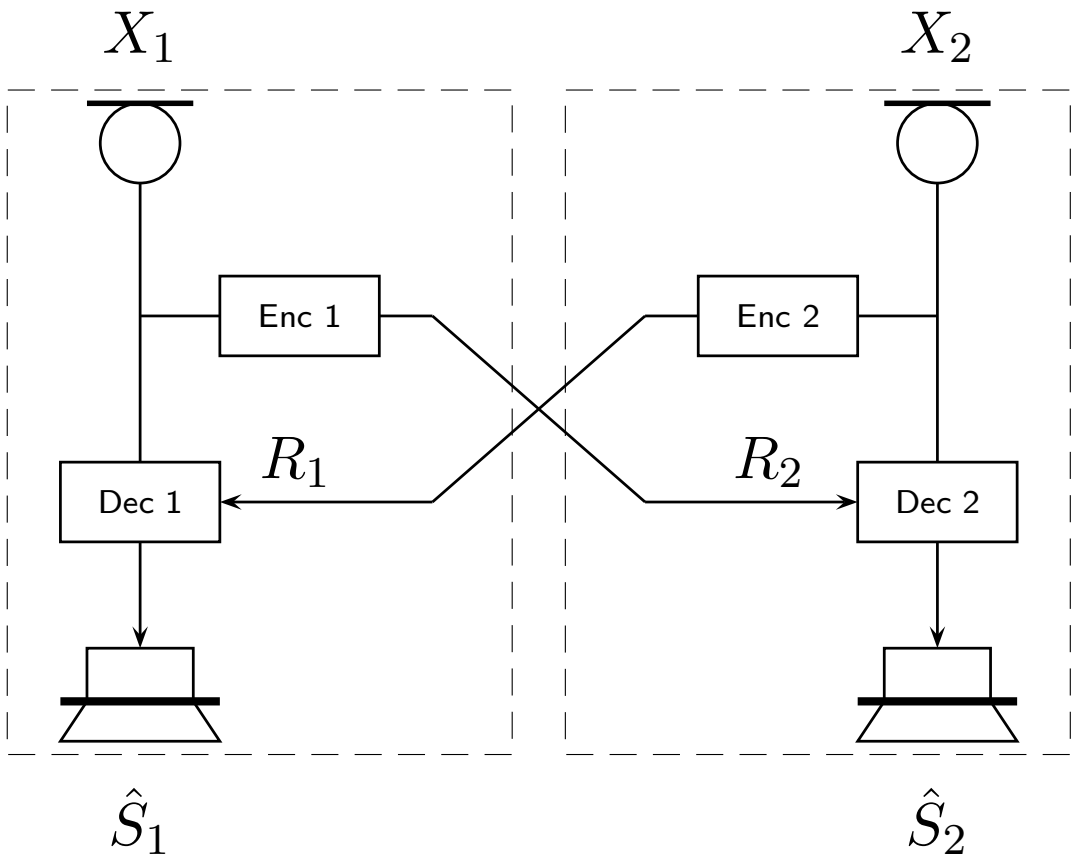
The Rate-Constrained Hearing Aid Problem (2/3)

Local perspective



The Rate-Constrained Hearing Aid Problem (3/3)

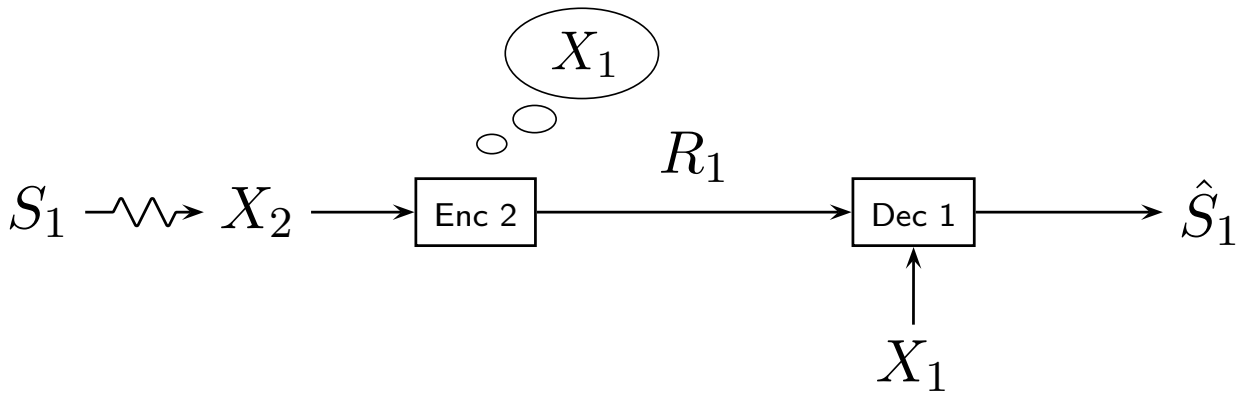
Global perspective



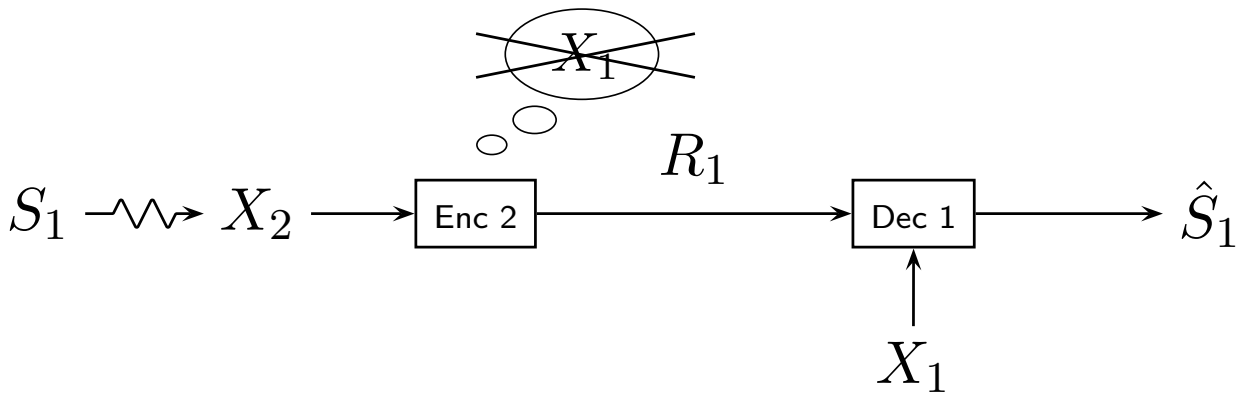
Remote Source Coding with Side Information

Two classes of coding strategies

- Side-information-aware (SIA) coding:



- Side-information-unaware (SIU) coding:



Gain-Rate Analysis (1/7)

Local perspective

- Gain-rate functions

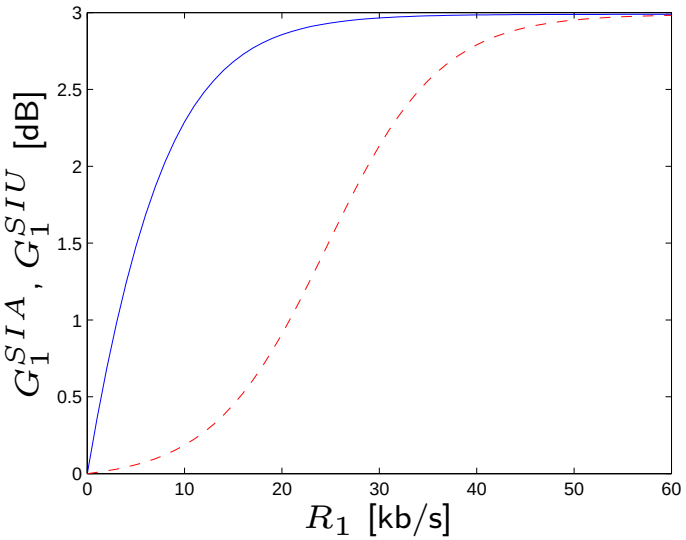
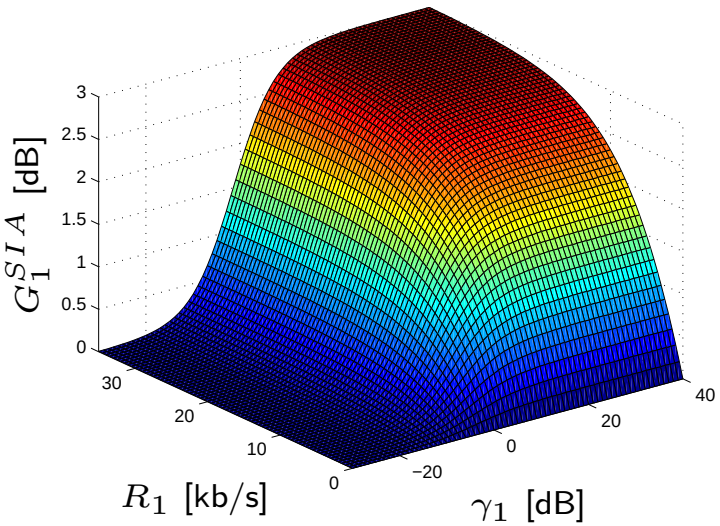


Figure: Typical gain-rate function with SIA coding (plain) and SIU coding (dashed).

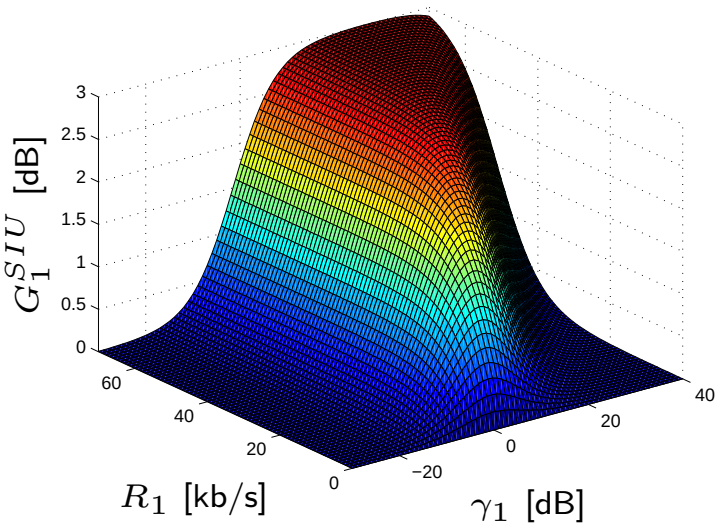
Gain-Rate Analysis (2/7)

Local perspective

- Gain-rate functions



(a)



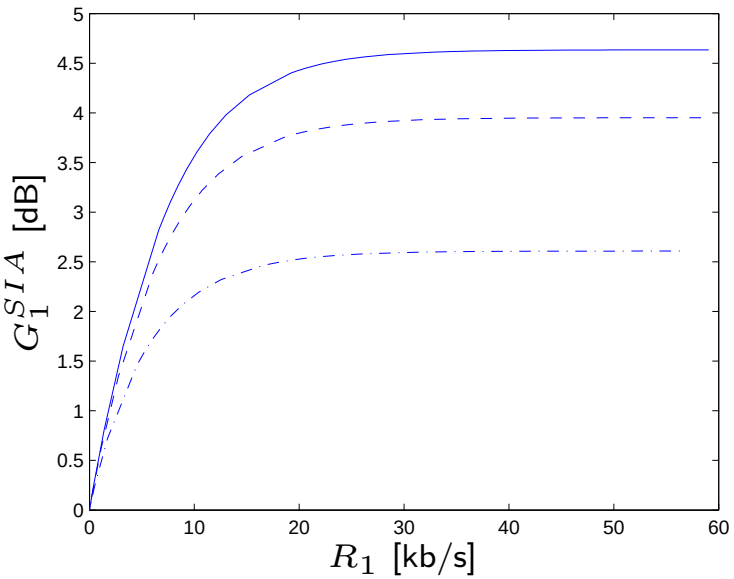
(b)

Figure: Typical gain-rate functions. (a) SIA coding. (b) SIU coding.

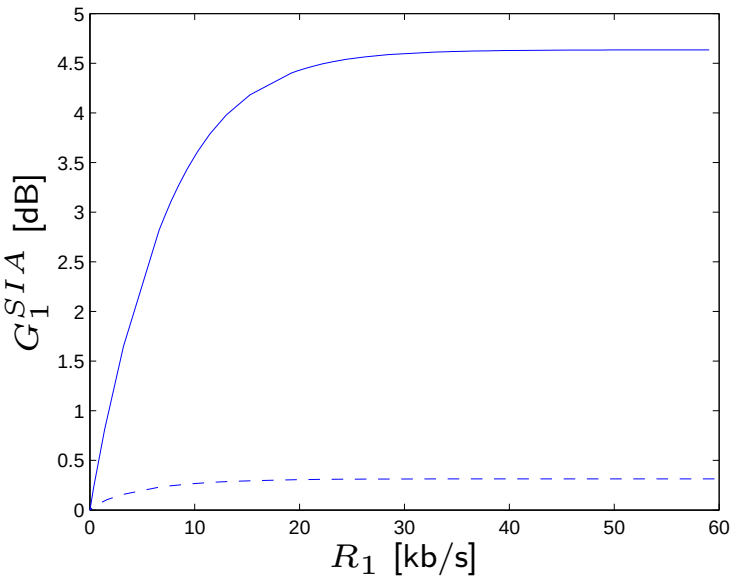
Gain-Rate Analysis (3/7)

Local perspective

- Gain-rate functions



(a)



(b)

Figure: Gain-rate functions with SIA coding. (a) $\alpha_I = 5, 8, 10$ [deg] (bottom to top). (b) $d = 0.2$ [m] (plain) and $d = 0.02$ [m] (dashed).

Gain-Rate Analysis (4/7)

Local perspective

- Optimal rate allocation across frequencies

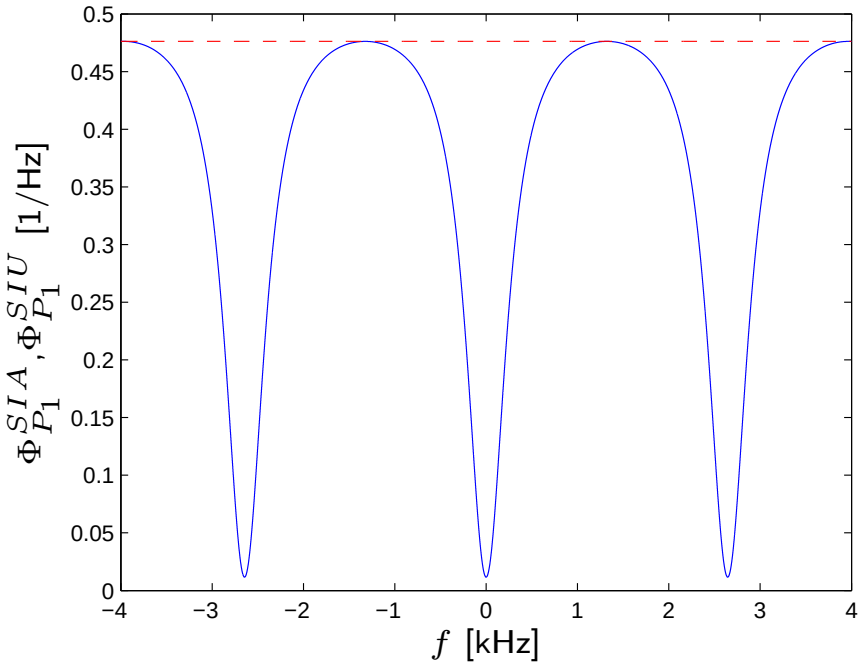
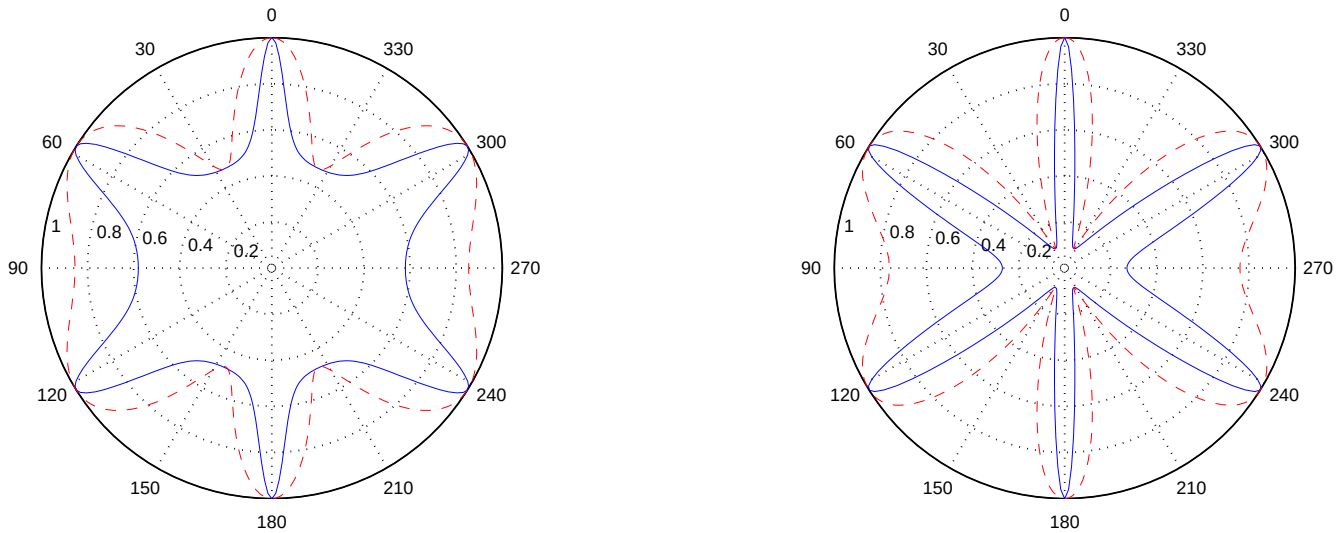


Figure: Reverse "water-filling" power spectral density with SIA coding (plain) and SIU coding (dashed).

Gain-Rate Analysis (5/7)

Local perspective

- Rate-constrained directivity patterns (RCDP)



(a) (b)

Figure: Typical RCDP with SIA coding (plain) and SIU coding (dashed) at $f = 2000$ [Hz] with $d = 0.2$ [m]. (a) $R_1 = 0.1$ [b/s/Hz] and (b) $R_1 = 1$ [b/s/Hz].

Gain-Rate Analysis (6/7)

Global Perspective

- Optimal rate allocation between the hearing devices

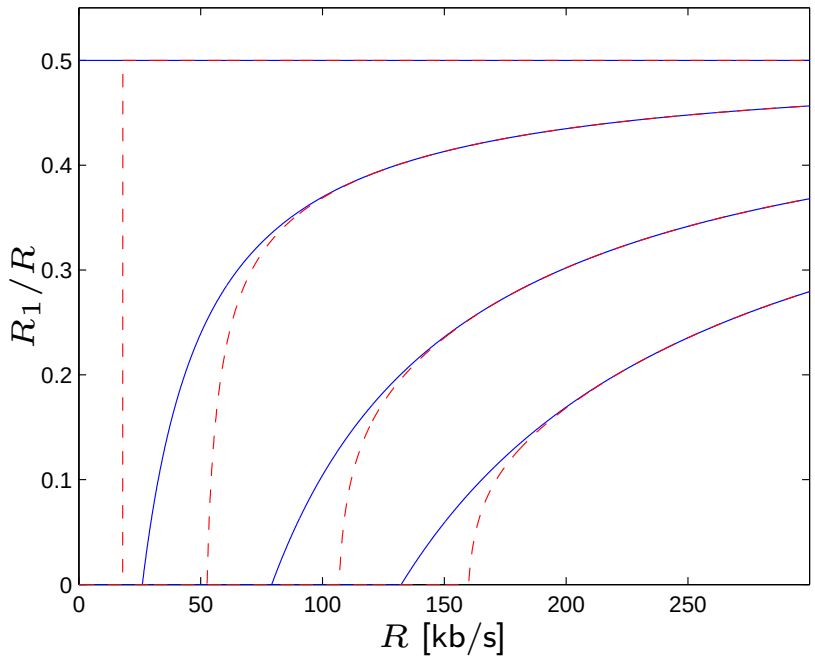


Figure: Rate allocation benefitting to hearing aid 1 with SIA coding (plain) and with SIU coding (dashed) for different SNRs.

Gain-Rate Analysis (7/7)

Also ...

- Head-shadow effect
- Perceptual weighting operator
- PSDs from speech excerpts

Conclusions

To conclude

- Identification of the problem
- Local & global perspectives
- Gain-rate characterization for SIA and SIU coding
- Optimal rate allocation policies
- Numerical results

Thanks for Your Attention

Questions ?